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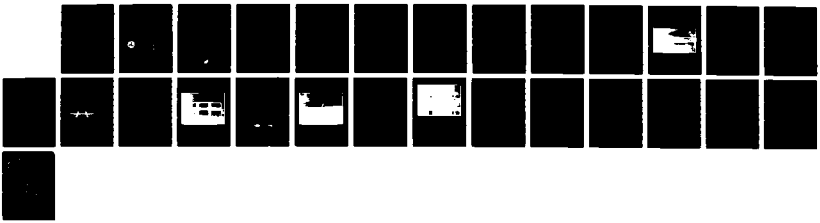

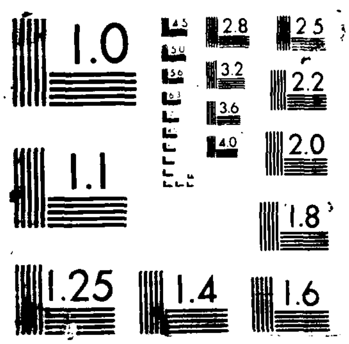
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Report No. CG-D-21-87

ST. LOUIS HARBOR
ELECTROLUMINESCENT (EL) BRIDGE LIGHTING PROJECT

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AND
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FINAL REPORT
MARCH 1987

Prepared for:

U.S. Department Of Transportation
United States Coast Guard
Office of Engineering and Development
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16. Abstract

In March 1986, Coast Guard Research and Development Center engineers deployed two prototype electroluminescent (EL) lighting arrays on the main span of the Poplar Street Bridge in St. Louis Harbor. The objective was to demonstrate the concept of extended light sources as applied to aids-to-navigation engineering. These extended light sources were designed to assist south-bound tug pilots in identifying and safely transiting the main bridge span on the Missouri side of the Mississippi River. In prior years, pilots had experienced difficulty transiting St. Louis Harbor during the high water season, with the Poplar Street Bridge being involved in at least two serious tug/tow incidents and numerous minor ones. No accidents have been reported since the prototype arrays were deployed in March 1986. User feedback concerning the EL arrays was consistently positive. The report describes the design, fabrication and deployment of the EL array, as well as reasons for perceived improvement in signal effectiveness.

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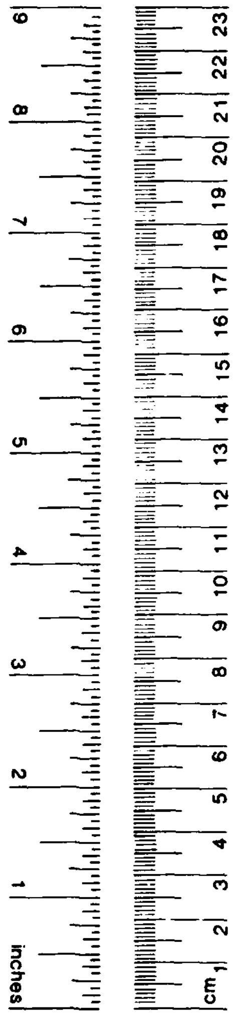
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

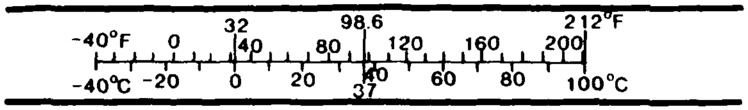
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25. SD Catalog No. C13 10.286



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ACKNOWLEDGEMENTS

We gratefully acknowledge others who were instrumental to successful conduct of the project. Mr. Roger Wiebusch, Chief, Second Coast Guard District Bridge Branch, was our point of contact in St. Louis; his assistance to us in coordinating various aspects of the project was invaluable. The River Industry Advisory Committee provided much needed professional user input during the design phase. Missouri State Highway Department personnel were extremely cooperative, operating the bridge monorail cart and providing traffic control on several occasions and assisting with the array electrical hookup. The Coast Guard Marine Safety Office gave support during the planning and deployment phases; Coast Guard Base St. Louis allocated workspace for the project engineer and assisted with assembly of the two lighting arrays. Finally, river pilots who returned completed questionnaires provided feedback vital to assessment of user response to the unconventional electroluminescent bridge lighting concept.

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1.0 INTRODUCTION

In March 1986, Coast Guard Research and Development Center engineers deployed two prototype electroluminescent (EL) lighting arrays on the main span of the Poplar Street Bridge in St. Louis Harbor. The objective was to demonstrate the concept of extended light sources as applied to aids-to-navigation engineering. These extended light sources were designed to assist south-bound tug pilots in identifying and safely transiting the main bridge span on the Missouri side of the Mississippi River. In prior years, pilots had experienced difficulty transiting St. Louis Harbor during the high water season, with the Poplar Street Bridge being involved in at least two serious tug/tow incidents and numerous minor ones. No accidents have been reported since the prototype arrays were deployed in March 1986. User feedback concerning the EL arrays was consistently positive; however, actual tests of piloting performance were beyond the scope and budget of the project.

2.0 BACKGROUND

2.1 Electroluminescent Lamp Technology

Coast Guard interest in electroluminescent (EL) lamps was sparked in 1981 by Air Force efforts to develop improved runway landing lights using EL lamps[1]. Coast Guard Research and Development Center engineers procured available EL lamps and power inverters from various manufacturers and became familiar with photometric, colorimetric, and electrical aspects of EL technology. While EL lamps are expensive and have luminous efficiencies much lower than incandescent lamps of equal input power, they have several

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[1] Pieroway, Chesley S., "Electroluminescent Lighting Applications", USAF report, Wright-Patterson AFB, OH, October 1981.

characteristics which are potentially exploitable in the design of visual aids to navigation[2,3]:

a. EL lamps do not fail catastrophically; luminous output initially shows a rapid decay, then exhibits a very gradual decay over a useful lifetime of several thousand hours.

b. EL lamps are Lambertian sources, with all light emitted in the forward hemisphere.

c. EL lamp luminous output can be adjusted by changing lamp input voltage or frequency. Either of these methods can be used to compensate for the decay of luminous output with lifetime.

d. EL lamps radiate very little heat (IR radiation).

e. EL lamps are very thin (1/32") and are conformable to curved surfaces.

f. EL lamps are rugged and can tolerate rough treatment and severe environmental conditions.

g. EL lamps are available in several colors (green, yellow, orange, white and red); chromaticity is determined by the phosphor mix during fabrication.

2.2 St. Louis Harbor Tug/Tow Incidents

In April 1983 a four-barge tow being pushed downriver collided with a pier supporting the Poplar Street Bridge (Figure 1) in St. Louis Harbor[4] Crude oil spilled, ignited, and caused fires along two miles of Illinois waterfront. Two of the barges broke loose and collided with other barges and shore facilities downriver. Damages were estimated to total about $9 million. The National Transportation Safety Board (NTSB) determined probable cause to

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2 Winslow, T. S., "Investigation of Electroluminescent (EL) Lighting", Interim report, USCG R&D Center, June 1982.

3 Winslow, T. S., "Investigation of Electroluminescent (EL) Lighting", Interim report, USCG R&D Center, February 1984.

4 "Ramming of the Poplar Street Bridge by the Towboat M/V City of Greenville and its Four-Barge Tow St. Louis, Missouri, April 2, 1983", Marine accident report, NTSB, Acc. No. PB83-916410, 29 November 1983.

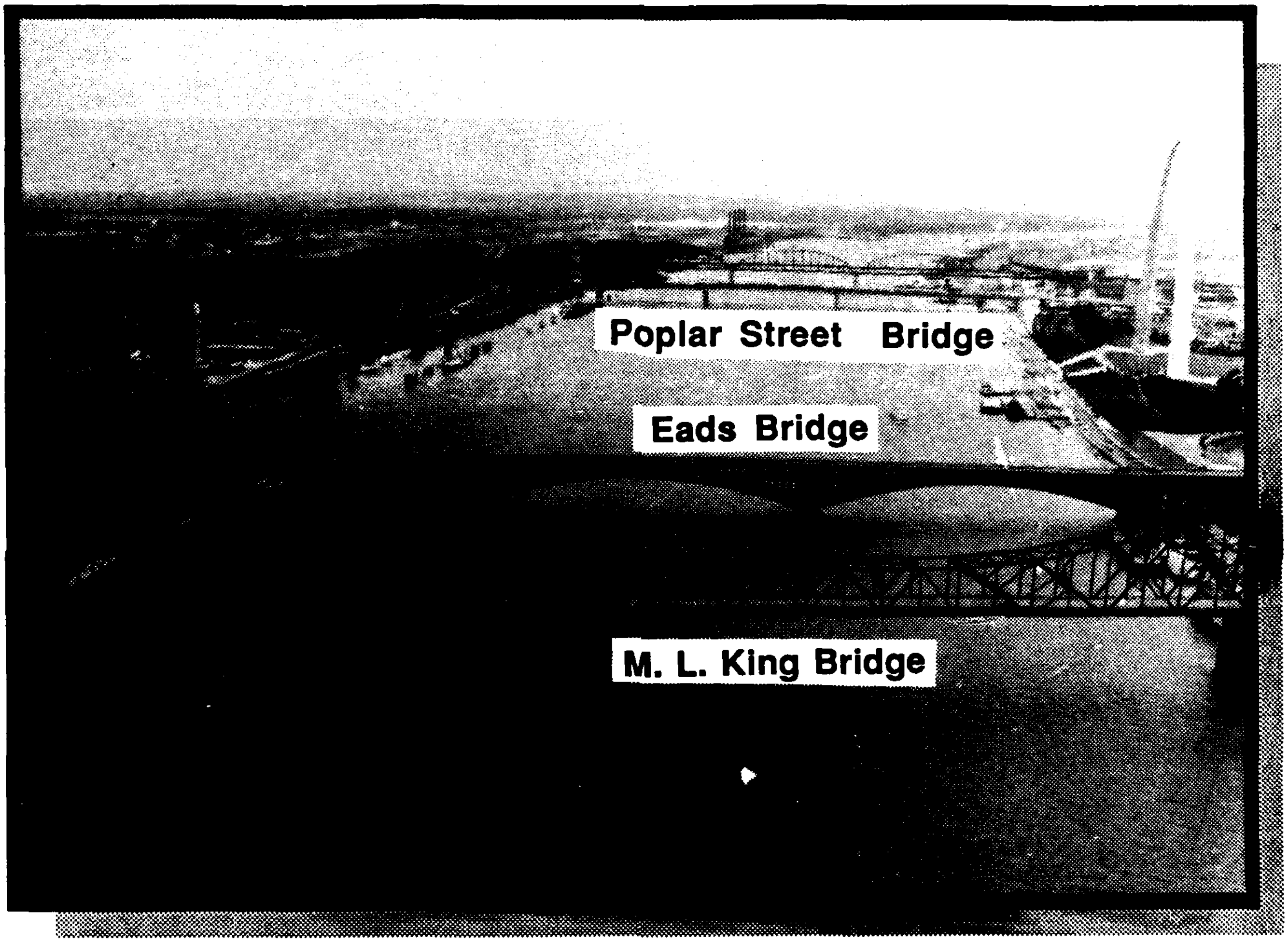

FIGURE 1. BIRD'S-EYE VIEW OF ST. LOUIS HARBOR

be "failure of the operator of the towboat ... to identify the main navigation span of the Poplar Street Bridge in time to align his tow for passage through the span"[5].

NTSB representatives visited the Coast Guard Research and Development Center in 1984 to discuss the incident and inquire about alternative lighting schemes for the Poplar Street Bridge. Several incidents in recent years involving tows transiting the bridge had led to the conclusion that more conspicuous lights were needed on the main span. Problems most often had been reported by south-bound tows during the high water season, when fast water and decreased bridge clearances reduced allowable reaction times and margins for pilot error. Electroluminescent lighting was proposed as a possible alternative to the existing Poplar Street Bridge lighting.

2.3 Extended Sources and Background Lighting

Discussions in St. Louis with Coast Guard officials and members of the maritime community confirmed south-bound tugboat pilots often reported difficulty in identifying the main span (as opposed to the auxiliary span) of the Poplar Street Bridge. Difficulty was attributed to several factors:

a. Background lighting from the Illinois shoreline and bridge roadway lighting.

b. Similar navigation lights marking both spans.

c. Relatively low-powered and/or dirty navigation lights marking both bridge spans.

d. Obscuration of Poplar Street Bridge lights by bridge structures approximately 0.8 miles upriver (when the pilots were still upriver of the offending bridges).

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[5] Ibid.

e. Obscuration of the lights by shore structures due to a bend in the river approximately 1.0 miles upriver.

f. A tendency to fix on the auxiliary span since the angle required to safely transit the Eads Bridge 0.8 miles upriver lined the tows up on the auxiliary span.

g. Unfamiliarity with the St. Louis Harbor section of the Mississippi River.

h. Poorly trained or inexperienced pilots.

An extended source array marking the main span was considered the best approach for overcoming background lighting and providing a conspicuous visual signal. The idea was to provide a "stripe" of light that would unmistakenly be identified as a bridge marker. Local tugboat operators preferred a lighting scheme which would mark the channel boundaries of the main span rather than the center of the span. This scheme was not feasible under the limited scope of the project. Red EL lamps (which would have been required to conform to channel boundary marking convention) were not available, and access to the vertical supports was not convenient. The next best scheme was determined to be a green horizontal array marking the center of the main span.

3.0 PROTOTYPE LIGHTING ARRAYS

3. . Preliminary Experiment to Determine Array Configuration

Two preliminary 6-ft by 2-ft lighting modules were assembled and temporarily suspended from the Poplar Street Bridge railing while observers aboard a tugboat navigated downriver toward the lights. Representatives from the local pilot group, Second Coast Guard District Office, and Marine Safety Office in St. Louis were aboard the tug as observers to judge the effectiveness of different arrangements of the preliminary modules, as well as to determine the distance at which the modules could be detected.

An arrangement with both modules oriented horizontally and placed to each side of the existing main span center lights was preferred by the majority of observers. Visibility was good on the day of the test, and all observers also agreed the modules could be detected as soon as the main span of the Poplar Street Bridge came into view (i.e., when it was not obscured by the landscape). With the river stage at 15 feet, modules could be detected from a distance of about 1.6 miles. During high water, the main span of the Poplar Street Bridge is not visible until the observer passes under the Eads Bridge, 0.8 miles upriver of Poplar Street.

At the Research and Development Center, several linear EL arrays were fabricated and placed end-to-end to estimate perceived source dimensions at various distances. Length of the composite linear array was adjusted while two observers viewed the source at a range of one nautical mile. A linear dimension such that the array would appear as a line rather than a point when viewed with the unaided eye was sought, as this unique appearance of a navigation light in the harbor was considered necessary to effectively combat the background lighting problem. The range of one nautical mile was chosen to allow pilots sufficient time to identify the Poplar Street Bridge main span prior to passing under the Eads Bridge. From this field experiment came the eventual lighting configuration: two 21-ft arrays 20 inches in height, centered about the existing main span center lights, with a spacing of 15 feet between the two arrays.

3.2 Design and Construction

Each 21-ft array was made up of 5 separate lighting modules, each 4-ft by 20-in. Figure 2 depicts the design of a single module, with light generated by six 7-in by 14-in green EL lamps. Green

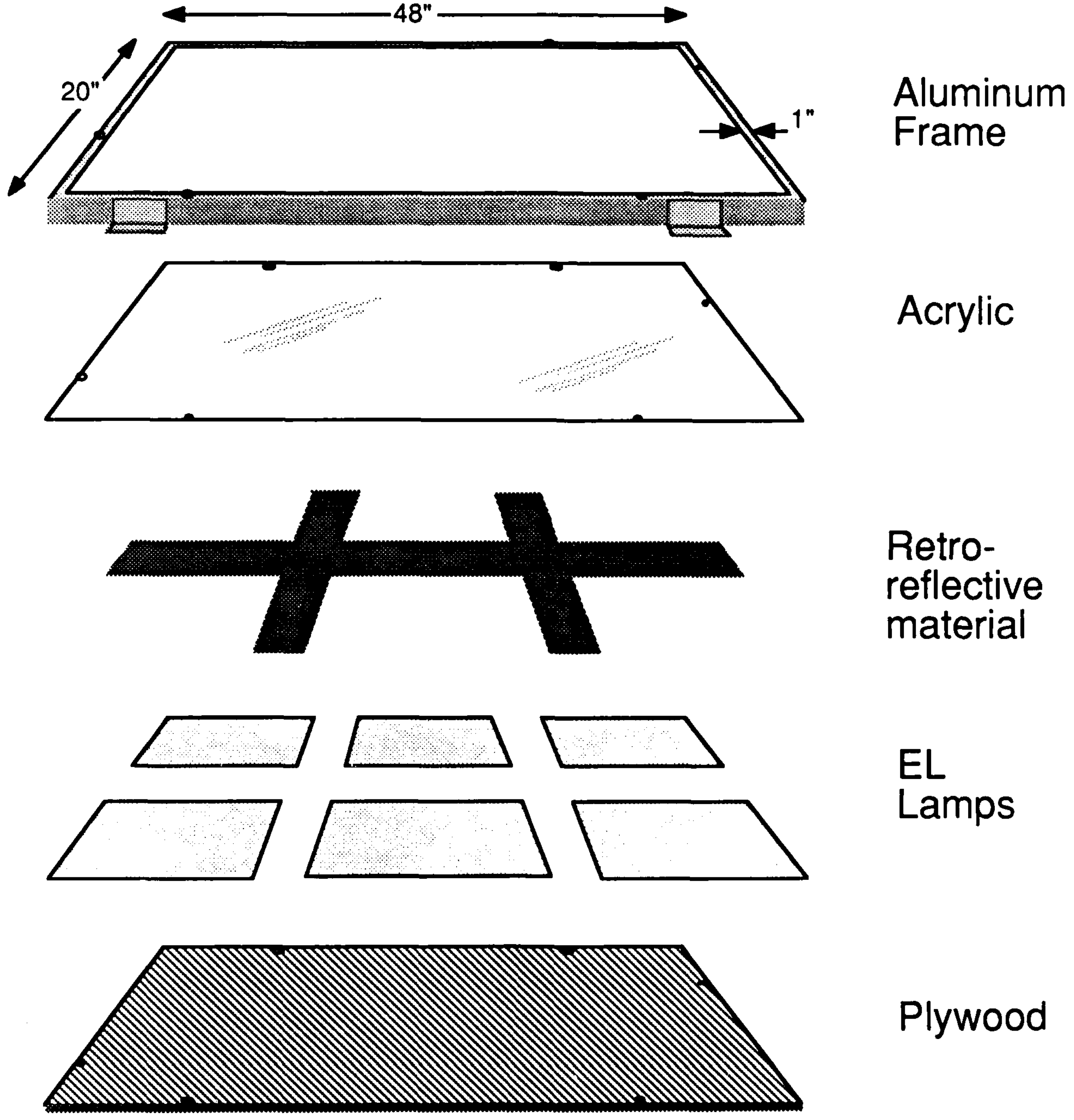

FIGURE 2. CONSTRUCTION OF EL MODULE

retroreflective material, in 4-in strips, was placed between individual lamps as a back-up system in the event of electrical disruption. The lamps and retroreflective material were sandwiched between a clear acrylic sheet and treated plywood substrate, with all wiring inset into routed channels to ensure good fit. The "sandwich" was set into a light aluminum angle frame and securely bolted to the frame. RTV silicone was applied liberally at the sandwich-frame interface to protect the lamps and wiring from moisture intrusion. The completed modules were then subjected to temperature changes and high humidity in an environmental chamber to verify that all joints were properly sealed. A fully assembled module is shown in Figure 3.

Two 21-ft by 20-in arrays were assembled with five modules each. Each array support structure (Figure 4) was designed to support an additional 300-lb load placed at the array center, to provide an appropriate safety factor. Modules within each array were wired such that each of the 30 EL lamps was parallel to the other 29. This ensured that failure of one or more lamps would not affect performance of other lamps in the system.

3.3 Installation

The arrays were bolted to the bridge superstructure by a local contractor. Wiring was completed by the Coast Guard project engineer, with 120-VAC power supplied by a custom designed transformer connected to the existing bridge 440-VAC system. The entire lighting system draws approximately 2 amperes and is fused to protect the transformer and bridge electrical system. Arrays are partially protected from the weather by the overhanging roadway structure and are accessible for inspection/repairs by a rail car that traverses the bridge superstructure. Figure 5 is a photograph of the Poplar Street Bridge with the EL arrays in

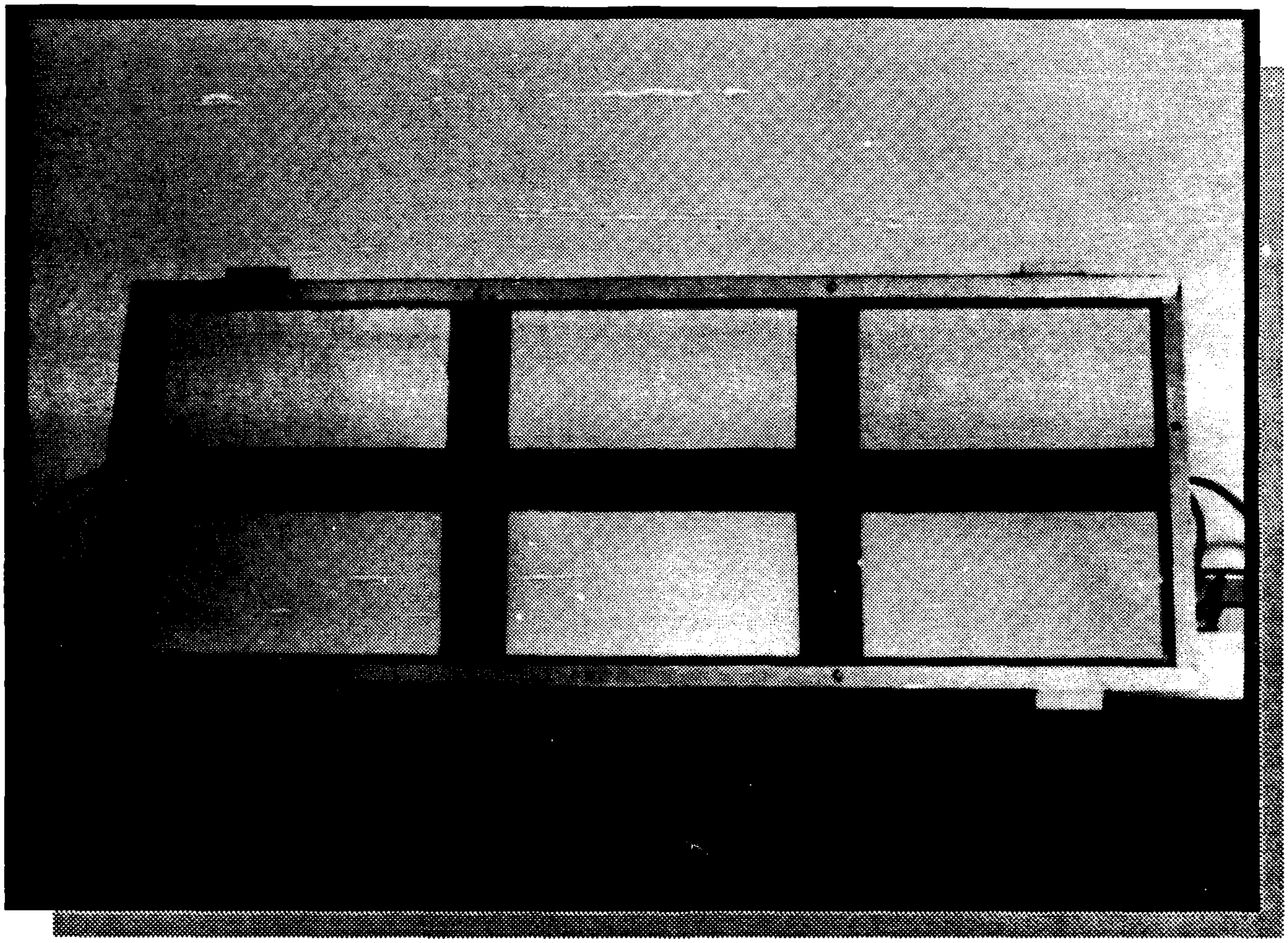

FIGURE 3. COMPLETED EL MODULE

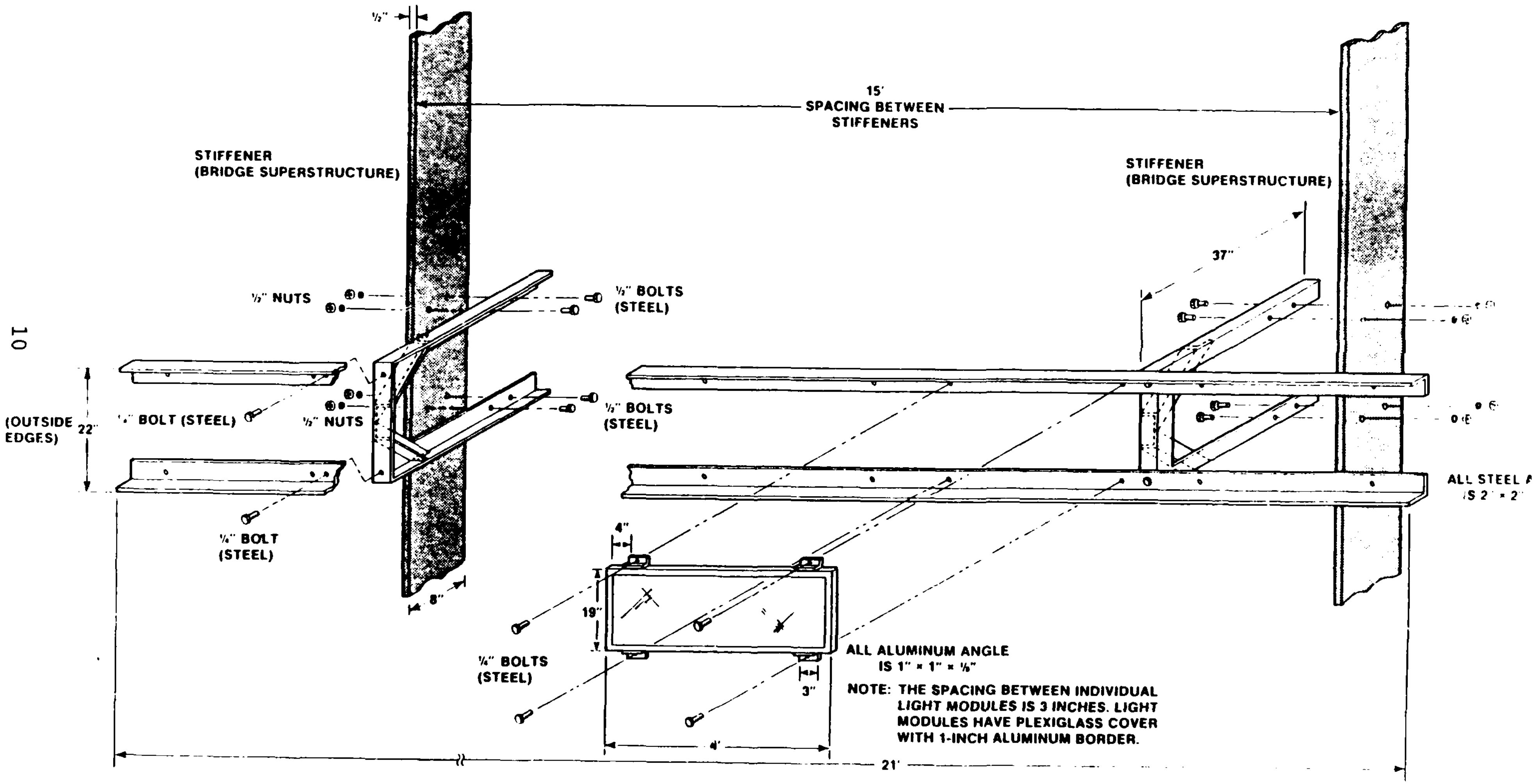

FIGURE 4. DESIGN OF MOUNTING SYSTEM

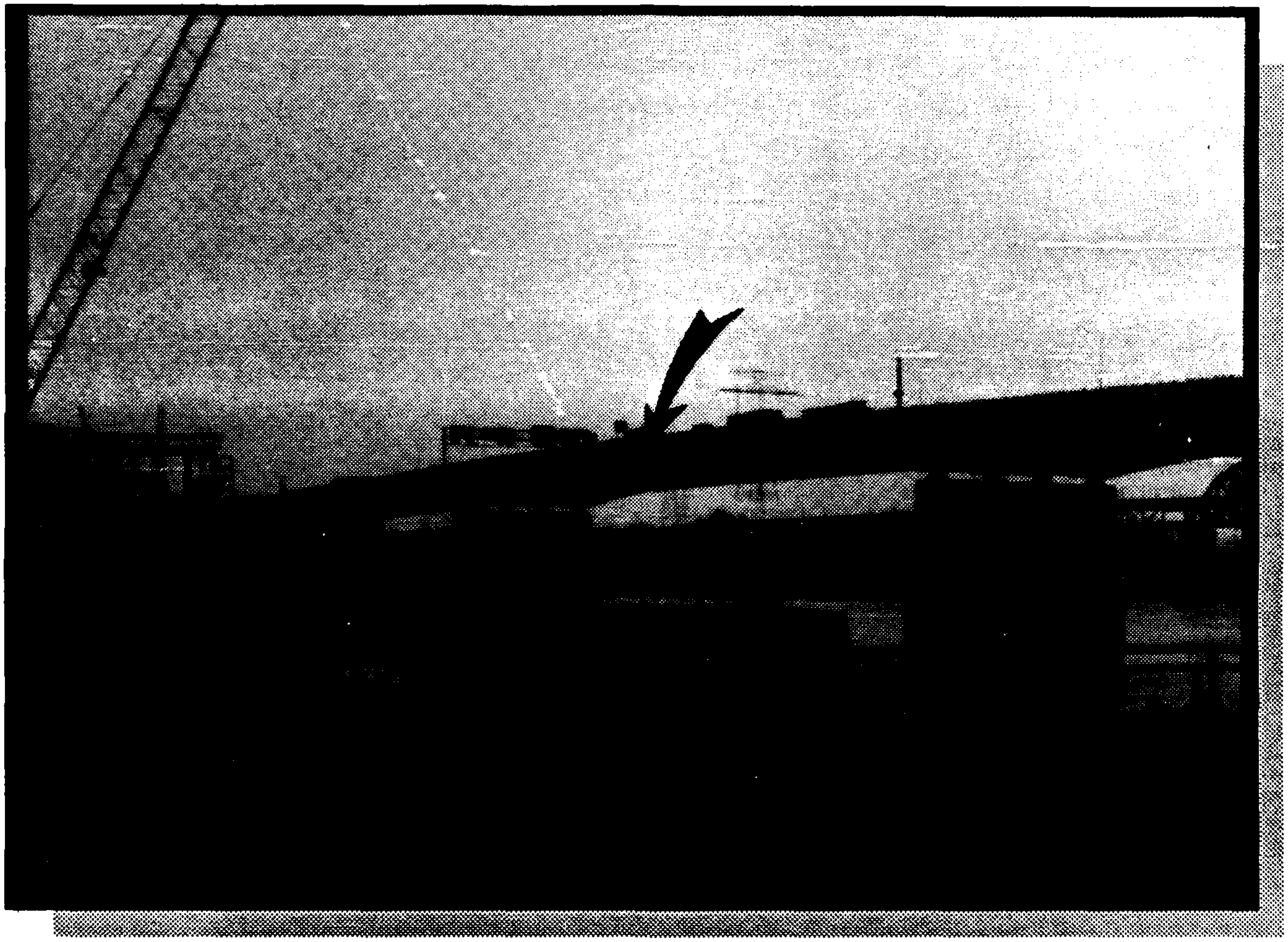

FIGURE 5. DAYTIME VIEW OF MOUNTED EL ARRAYS

place. Figure 6 shows the arrays as seen at night from an approaching tug boat.

4.0 QUESTIONNAIRES

Tug operators traveling south with planned nighttime transits of St. Louis Harbor were given questionnaires at a lock several miles upriver of St. Louis; respondents returned questionnaires to the Second Coast Guard District. Two different versions of the questionnaire (Appendix A) were actually distributed. Nine responses were obtained to Questionnaire #1. Twenty-six responses were obtained to Questionnaire #2.

On average, the EL system was first detected at a point 1.4 miles upriver of the Poplar Street Bridge. Of the 14% of respondents reporting hazy conditions during their transits, average detection distance was also 1.4 miles. Of the 9% reporting rain during transit, average detection distance was 1.2 miles.

Eighty-six percent judged the EL system to be seen very well against the background lighting, while 6% felt the system was only somewhat visible, and 3% felt they were poorly seen. Ninety-seven percent of respondents believed the EL arrays were more visible than existing midchannel lights. When asked if the EL system should become a permanent aid to navigation on the Poplar Street Bridge, 97% answered it should remain.

When asked how EL arrays could be improved, 23% thought the lights should be brighter, 9% wished they flashed, and 3% requested a different color. Other suggestions were to add red vertical modules to the left pier (6%) and place additional modules on the Eads and M. L. King bridges (3%). Fifty-four

FIGURE 6. NIGHTTIME VIEW OF MOUNTED EL ARRAYS

percent of respondents liked the system the way it was designed. In fact, one respondent wrote: "This is an excellent aid to navigation. No improvement is necessary".

5.0 DISCUSSION

The extended source EL lighting on the Poplar Street Bridge was judged an improvement over existing main span lights by nearly all people familiar with the problems of navigation in St. Louis Harbor. Uniqueness of the extended source display contributed to this perceived improvement. A typical aid-to-navigation marking a bridge is an incandescent lamp surrounded by a filter and lens. From a short distance, the light appears as a point source, similar in shape and size to all other navigation lights and most of the background lights. A tug pilot, searching for the main span of the Poplar Street Bridge, is searching for three vertically oriented white point sources. Since most of the background lights are similar in appearance, the pilot must consider all lights in the vicinity of the main span as potential condidates for aids-to-navigation, and systematically reject from his search irrelevant background lights. The amount of time and effort expended in finding the main span will be related to the number of competing background lights.

When EL arrays are placed across the main span, the task of finding the relevant aid is made easier, since few, if any, background lights are similar in shape and orientation. The reduction in time and effort required to find aids-to-navigation translates into lower risk associated with a transit and a perceived improvement in the aid-to-navigation.

Two points must be kept in mind when considering extended sources

on other bridges or in other situations. First, electroluminescent lighting is not the only available technology for creating extended sources. Displays similar to that on the Poplar Street Bridge can be made with fluorescent lamps, incandescent lamps, and light pipes[6]. Electroluminescent lighting was chosen because of its ease of implementation. Second, the extended source configuration on the Poplar Street Bridge was one of many possible arrangements to mark unambiguously the center span. Design of the lighting system was guided by intuition rather than empirical data. Other configurations may be as good or better than the one demonstrated in St. Louis.

One of the advantages of the EL system is that the intensity is high enough to give the desired detection range, but not so high as to prevent pilots from seeing beyond the Poplar Street Bridge. Intense light sources cause glare which obscures all features beyond the glare source. It may have been possible to improve conspicuity of the main span lights by making them more intense, but it would have caused complaints about glare. The EL array provided conspicuity through size rather than intensity.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Electroluminescent lighting arrays were judged to be more conspicuous than point sources for marking the center span of the Poplar Street Bridge in St. Louis, MO. The local maritime community believed it was easier to find the center span with the extended source than with the typical green and white point sources. An overwhelming majority of tug pilots passing through St. Louis preferred the EL array to point sources.

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6 Light pipes are acrylic tubes that emit light. A light source placed at one end of the tube and with a mirror and the property of total internal reflection, light is emitted uniformly along the length of the tube. This is a patented system manufactured by TIR Systems, Ltd.

Further research is required before extended sources are widely deployed in the field. Currently, no measure is commonly accepted to assess improvements in conspicuity. Moreover, little work has been done to optimize size, shape, and intensity of such sources to maximize conspicuity within engineering and fiscal constraints. These issues should be addressed in future work by measuring time to locate extended source targets with different amounts of background lighting. Tradeoffs among size, shape, and intensity can be assessed, as well as comparisons made between point and extended sources.

Moreover, since extended source displays can be made with several different technologies (fluorescent lamps, incandescent lamps, light pipes), the power, reliability, and servicing trade offs of these technologies must be addressed.

APPENDIX A

PILOT QUESTIONNAIRES

QUESTIONNAIRE #1

The Coast Guard has installed experimental green lighted panels on the upstream side of the main channel span of the Poplar Street Bridge, Mile 179.2, Upper Mississippi River. The panels extend 21 feet on each side of the green midchannel light and are two feet tall. A test will be conducted for approximately 6 months to determine whether the lighted panels aid mariners in identifying the channel span of the Poplar Street Bridge.

To assist us in evaluating the effectiveness of these panels please complete the following questionnaire, then fold, staple and mail it. The address and postage are already on the back of this page.

1. Date ____________________ 2. Name ____________________

3. Towboat Name ______________ 4. Company ______________

5. Time ____________________ 6. River stage ______________

7. Weather: (circle one) clear hazy cloudy snow,rain foggy

8. EL Panels first seen: (check best answer)

   North Market Street ______________

   Mullanphy Street ______________

   Other (fill in space) ______________

9. How well could the panels be seen against the background lighting? (circle one)

   not at all poorly very good

10. Are the panels more visible than the green navigation lights? (circle one)

   yes no

11. Did the panels help you identify the navigation span of the Poplar Street Bridge? (circle one)

   yes no

12. Should the panels be permanently installed? (circle one)

   yes no

13. How can we improve the panels? (circle answers)

   a. Brighter b. Larger c. Change color

   d. Flash it e. Change Location f. Other

QUESTIONNAIRE #2

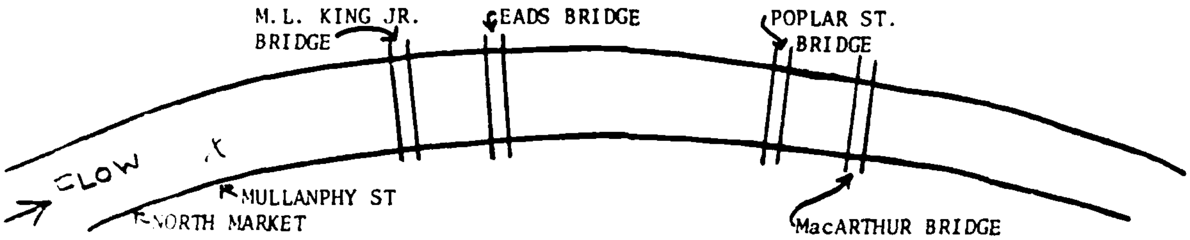
The Coast Guard has installed experimental green lighted panels on the upstream side of the main span of the Poplar Street Bridge, Mile 179.2, UMR. The panels extend 21 feet on each side of the green midchannel light and are two feet tall. A test will be conducted for approximately 6 months to determine whether the lighted panels aid mariners in identifying the channel span of the Poplar Street Bridge. To assist us in evaluating the effectiveness of these panels please complete the following questionnaire, then fold, staple and mail it. The address and postage are already on the back of this page.

1. Date ______________   2. Towboat ____________________________

3. Time ____________   4. River stage _________

5. Weather: (circle one)   clear   hazy   cloudy   snow,rain   foggy

6. On the following diagram of the river, please indicate where you were when you were first able to positively identify the green panels:



7. How well could the panels be seen against the background lighting? (Mark correct box on scale below):

1	2	3	4	5
not at all		somewhat		very well

8. How well could you distinguish the three white main span lights? (Mark correct box on scale below):

1	2	3	4	5
not at all		somewhat		very well

9. How would you rate the visibility of the green panels compared to the green midchannel lights. (mark correct box on scale below):

1	2	3	4	5
not at all		somewhat		very well

10. Should the panels be permanently installed? (circle one)   yes   no

11. How can we improve the panels? (circle answers)

a. Brighter   b. Larger   c. Change color
d. Flash it   e. Change Location   f. Other

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